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EVALUATION OF MULTIPLE POLARIZED RADAR IMAGERY FOR THE DETECTION OF SELECTED CULTURAL FEATURES

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HOUSTON, TEXAS

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WASHINGTON, D.C. 20242

Interagency Report
NASA-130
October 1968

Mr. Robert Porter
Acting Program Chief,
Earth Resources Survey
Code SAR - NASA Headquarters
Washington, D.C. 20546

Dear Bob:

Transmitted herewith is one copy of:

INTERAGENCY REPORT NASA-130

EVALUATION OF MULTIPLE POLARIZED RADAR IMAGERY

FOR THE

DETECTION OF SELECTED CULTURAL FEATURES*

by

Anthony J. Lewis**

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Sincerely yours,

William A. Fischer
Research Coordinator
EROS Program

*Work performed under NASA Contract No. W-12589 and Task 160-75-01-32-10
**University of Kansas, Center for Research, Inc., Engineering Science Division (CRES)

UNITED STATES

DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

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EVALUATION OF MULTIPLE POLARIZED RADAR IMAGERY FOR THE DETECTION OF SELECTED CULTURAL FEATURES*

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INTRODUCTION

(U) The use of radar as a remote sensor is a relatively new innovation for the geoscientist. The capabilities which render radar as especially useful tool to geoscience are as follows: 1) independence from solar illumination and most atmospheric conditions, 2) ability to scan wide swaths of terrain, 3) presentation of collected data on a continuous strip of imagery, 4) resolution characteristics even at orbital altitudes to resolve a cell 15 meters by 15 meters. Multifrequency and multipolarization radar reconnaissance has been initiated recently to increase the information collecting capabilities of imaging radar. By utilizing various frequency bands between .20 and 40 gc and the total polarization matrix more data are obtained, and as a result interpretations can be made with a higher level of confidence than with a single frequency, single-polarized radar image.

(U) A NASA Sponsored study is being conducted at the University of Kansas Center for Research in Engineering Science (CRES) to evaluate the use of multiple-polarized K-band radar imagery for geoscience purposes. This evaluation uses four types of polarization, namely:

1. Horizontal transmit, horizontal receive (HH)
2. Horizontal transmit, vertical receive (HV)
3. Vertical transmit, vertical receive (VV)
4. Vertical transmit, horizontal receive (VH).

Radar imagery produced by transmitting and receiving in the same polarization mode (HH and VV) is also referred to as "like-polarized", whereas when two modes (HV and VH) are used the imagery is termed "cross-polarized" or "orthogonally depolarized."

(U) Theoretical studies (Fung, 1965) have substantiated the possibility of differences of received signal amplitudes between the two like-polarizations (HH and VV) and between the cross-polarizations (HV or VH) and the like-polarizations (HH or VV). Due to reciprocity amplitude differences between the two cross components (HV and VH) should not exist. The degree of depolarization of the return signal has formulated to be a function of 1) object orientation (polarization) in both the azimuthal and range direction, 2) the Fresnel reflection coefficient, which is in turn a function of the complex dielectric constant and the angle of incidence. Therefore, scanning with multiple-polarized radar provides the geoscientist with information concerning the complex physical properties of the target not available from one type of polarization alone.

Previous evaluations of radar imagery by geoscientists have been concerned primarily with the like-polarized component. Comparatively few studies are available which evaluate both cross- and like-polarized components. One such study by L. F. Dellwig and R. K. Moore (1966) showed a use of multiple-polarization radar imagery in the field of geology. They were able to distinguish alluvial material derived from various sources, and to differentiate rock types in areas of apparent similarity by comparing cross- and like-polarized imagery of the Pisgah Crater area in California. Their preliminary investigations also indicate that the absolute identification of each rock type on the basis of contrasts in return from various combinations of polarized radar imagery may be feasible. Dellwig and Moore suggest that differences between cross- and like-polarized return may be lithology dependent but that they are more probably a function of surface roughness. Cooper (1966) and Gillerman (1967) reported a striking difference in radar return between like- and cross-polarized images in several areas dominated by silicon-rich outcrops. More specifically, the silicon-rich (volcanic glass) areas produced a lower return on the cross- than the like-polarized image in relation to the surrounding environment. Field checking revealed the variation in relative return to be a complex function of surface roughness, topography, vegetation, and rock composition and not a simple relationship with the percentage of silicon in the outcrop as previously expected (Gillerman, 1967).

Papers by Morain and Simonett (1966) and Ellermeier, et al. (1966) presented at the Fourth Symposium on Remote Sensing of Environment at the University of Michigan, respectively involved the interpretation of multiple polarized imagery for vegetation analysis and the general applications of multiple polarized imagery in interrelated fields of geoscience. Morain (1967) later reported visually detected variations in relative tonal signatures on the like- and cross-polarized radar imagery from two vegetation types, chaparral shrub and sagebrush, in the vicinity of Horsefly Mountain, Oregon. A follow-up study by Morain and Simonett (1967) utilized electronic techniques to determine the radar backscatter and probability density function on the cross- and like-polarized imagery from natural plant communities. They concluded that detection was enhanced and mapping facilitated by the use of both electronic techniques and multiple polarized imagery.

(U) Studies are also presently being conducted at the Center for Research, University of Kansas using multiple polarized radar imagery for the detection and discrimination of crop types. It has been found that depolarization is dependent in part upon the crop type and its stage of development. For example, depolarization of the radar signal is greater with headed sorghum than it is with sorghum prior to heading. Similar results were also found with alfalfa as it progressed to maturity. Other parameters are possible but to date have not been tested.

(U) The purpose of this study is to evaluate empirically and statistically the like-polarized (HH and VV) and orthogonally depolarized (HV and VH) components of K-band radar imagery for detection of cultural features. Only selected cultural features have been investigated. These are: 1) rural, urban, and agricultural patterns, and 2) transportation and communication nets. Subsequent related reports will cover the use of multiple polarized imagery in the sensing of physical features of the environment as well as aspects of the cultural landscape not dealt with in this report.

(U) Wherever possible interpretations presented in this report are based on field investigations and correlated with published maps. The differences between like- and cross-polarized images at first are few. Consequently it was decided to test statistically the nature of any differences between the several polarizations.

(U) The statistical observations of this report are based in part on an interpretation exercise utilizing like-polarized and orthogonally depolarized imagery of K-band radar presented to sixty-eight student observers with little or no previous experience interpreting radar imagery. Two groups at the University of Kansas, a Physical Geography lab section and the Geography Institute of Elementary Teachers, were selected to participate in an attempt to evaluate the two polarization components for the detection of cultural features. Each interpreter was supplied with four radar images, each of a different geographic area, two of which were like-polarized (HH) images and two of which were cross-polarized (HV) images. The images were distributed so that no one interpreter would receive two polarizations of the same geographic area and so that, although all would be working on the same geographic area, approximately half would have the same polarized image. Instructions (see Appendix I) accompanied the radar imagery and designated, for each area, the alloted time for interpretation and cultural features expected to be detected. Brief descriptions of the cultural features and several of their identifying signatures on radar imagery were also included. Results of the experiment were compiled and an analysis of variance computed to test for significant difference between the two polarization schemes.

(U) Other statistical measures were applied in evaluating multiple polarized imagery for the detection of spots of high intensity return in Maryland. The procedures varied from study area to study area. Three of the studies involved the counting of spots of high intensity return in selected geographic areas by several experienced radar interpreters. The total and average count of high intensity spots for each polarization was used for tentative evaluation of the four polarizations under study, whereas standard deviations were computed to test variation around the mean. The fourth study encompassed correlation of field data with radar imagery in an attempt to evaluate the influence of roof orientation and material on the four polarization schemes available. Buildings detected by one or more of the polarizations were compared with maps of roof orientation and material based on intensive field work. Findings were then presented in tabular form.

OBSERVATIONS

(U) In general, like-polarized K-band imagery is of better quality than the simultaneously recorded cross-polarized imagery, due in part to the greater dynamic range exhibited on the like-polarized imagery. Since the orthogonally depolarized (HV and VH) received signal is several db lower (approximately 10) than the like-polarized signal, it is necessary to increase the gain setting of the depolarized signal to an energy level comparable to the like-polarized signal. The increase in gain required to record the cross-polarized signal raises the noise level sufficiently to produce a grainy appearance on the depolarized image.

Rural and Urban Patterns

(C) In rural environments cross-polarized imagery is generally better for defining cultural objects such as farmsteads and transportation arteries (see Figure 1). Certain cultural objects such as bridges, stand out more than natural features on cross-polarized imagery because of their ability to return a relatively stronger orthogonally depolarized radar signal. The data from a number of preliminary studies in 1965-66 reveal that spots of high intensity return, interpreted as cultural objects, were more discernable on cross-polarized imagery. Results of one report (Lewis, 1966b) are shown graphically in Figure 2 indicating the predominance of high intensity spots on the cross-polarized imagery. In Figure 2, the near perfect alignment of spots between Laytonsville and Sunshine, Maryland on the cross-polarized image represents the location of a power

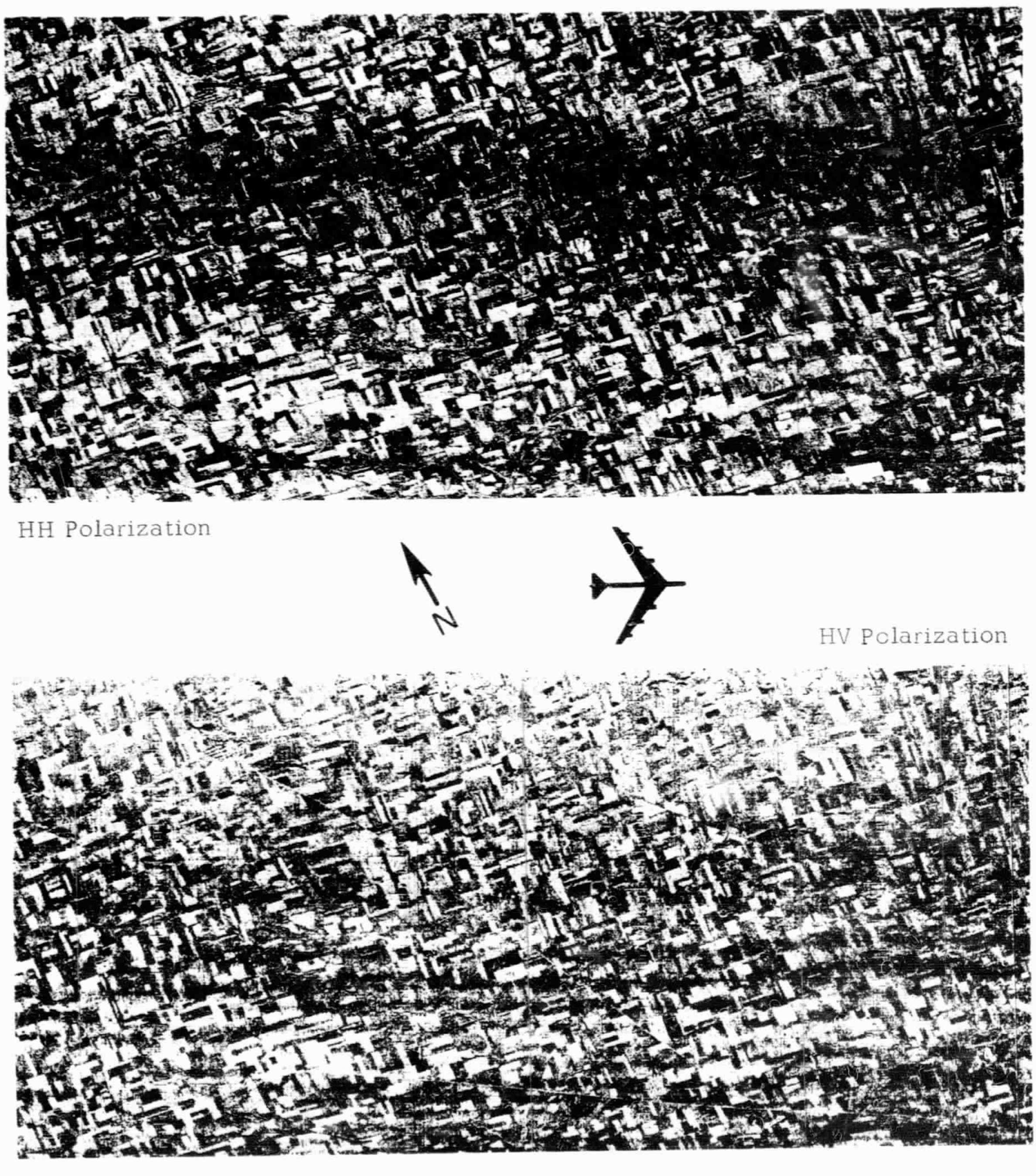

FIGURE 1. USE OF CROSS POLARIZED RADAR TO DETECT FARM BUILDINGS NEAR DAYTON, OHIO

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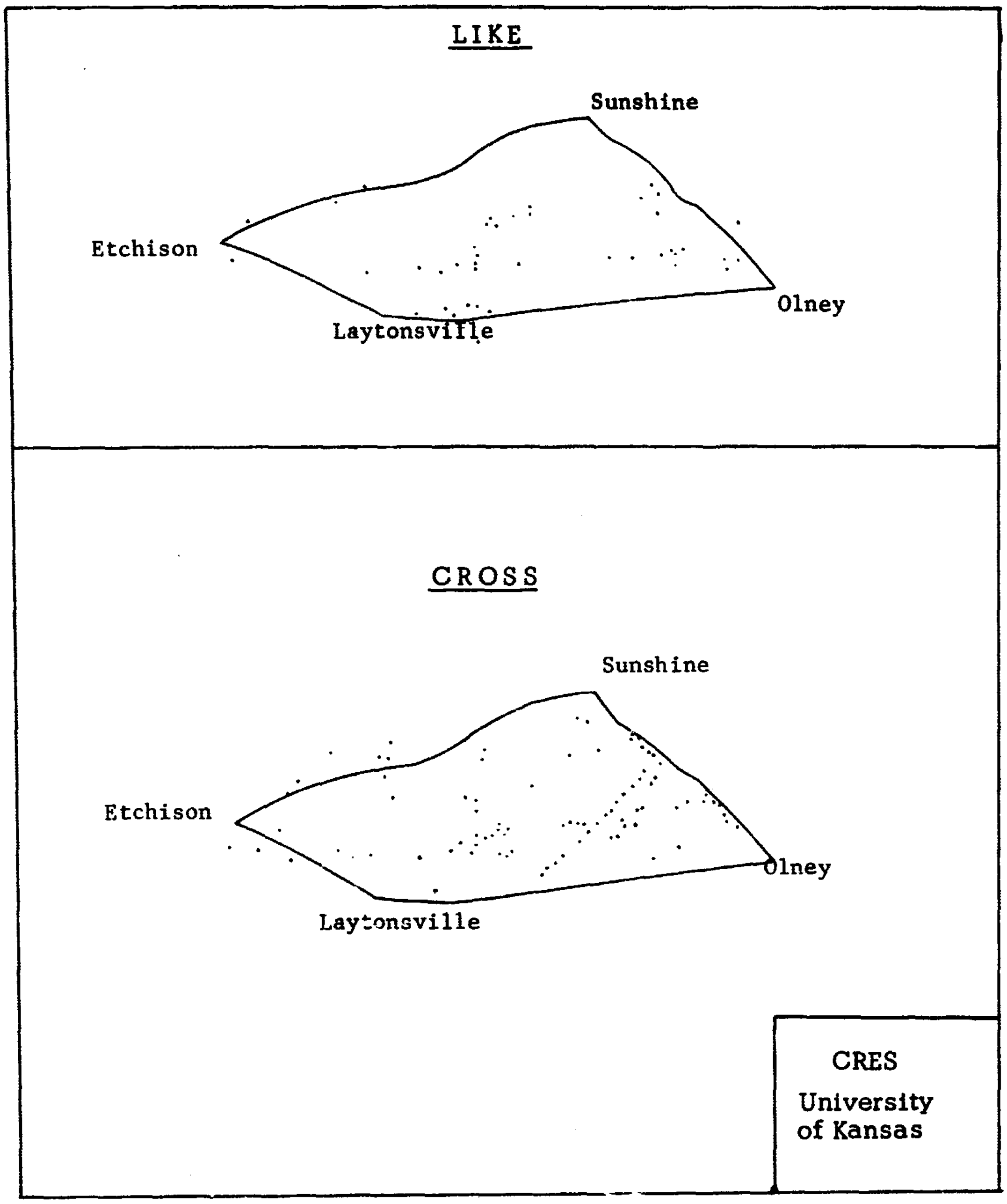

FIGURE 2. POINT CULTURAL FEATURES DETECTED ON TWO RADAR POLARIZATIONS, MONTGOMERY COUNTY, MARYLAND

transmission line not visible on the like-polarized image. A second unpublished study by Morain and Lewis (1966) evaluated the ability of four polarization modes for detecting cultural targets by tabulating the number of spots of high energy return in identical geographical locations. The areas were selected from unclassified K-band radar imagery of Frederick County, Maryland. The results help substantiate that cultural features, such as buildings, are more easily detected on the cross-polarized imagery than the like-polarized. The capability of the multiple polarized imagery for detecting buildings was tentatively categorized in the following order:

1. HV - Highest capability for detection
2. VH } Intermediate capability for detection
3. HH }
4. VV - Lowest capability for detection.

The classification of the VH in the same category with the HH and not with the HV is seemingly contradictory to reciprocity. However, reciprocity assumes parameters, such as quality of the imagery, direction and altitude of flight path, and viewing angle, which are constant, a condition not satisfied in the above experiment. A true test of reciprocity would require the four differently polarized images to be recorded simultaneously on the same flight, an experiment which to date has not been carried out and in part accounts for the apparent contradiction.

A third unpublished report (Lewis, 1966a) tested six different interpreters' ability to detect spots of high intensity return on four geographic areas in Frederick County, Maryland, two of which were scanned by HH and HV polarizations and two by VV and VH polarizations. In all four geographic areas the average number of spots detected was higher on the cross-polarized image (HV and VH) than the like-polarized image (HH and VV) ranging from 1.25 to 1.9 times as great (see Table 1). Even with the larger number detected on the cross-polarizations the standard deviations in three of the four areas were lower indicating a greater reliability in the detection of spots of high intensity return for the cross-polarized images.

Other related but independent studies by CRES personnel have involved the effect of building materials and roof orientation on the radar return signal in the Woodsboro-Walkersville, Maryland area. The results are tabulated in Tables 2 and 3 and further substantiate the increased detectability of certain cultural features on cross-polarized imagery and the advantage of scanning with more than one polarization. In all cases, regardless of roof orientation and material, the orthogonally depolarized image was equal to or better than the simultaneously received like-polarized image for the detection of buildings. These preliminary studies led on to adopt a systematic test procedure to document in a structurally acceptable fashion the character of the differences between polarizations for detecting cultural objects.

In urbanized areas the cross-polarized mode enhances the interpreter's ability to discriminate large shopping centers, institutional complexes, and industrial areas such as fertilizer plants, oil refineries, cement plants, rail stations or yards, and grain storage bins. All of these areas characteristically have a dearth of natural vegetation. It is interesting to note that the Central Business District (CBD), also characterized by a lack of natural vegetation does not seem to be more accurately delineated on the cross-polarized image than the like-polarized image. The results of the interpretation exercise presented to the physical geography lab section and Geography Institute for Elementary Teachers indicate that the CBD was better delineated on the HH polarization (see Table 4). A ratio of variance of 4.00 allows the null hypothesis to be rejected at the .05 level of confidence (see Table 5). A visual observation of the radar imagery of Lawrence, Kansas (Figure 3) also helps to verify that the CBD is more easily delimited on the like-polarized radar image than it is on the cross-polarized image.

Discrimination between residential sections that differ by age, building material, and/or roof shape is also more feasible on multiple

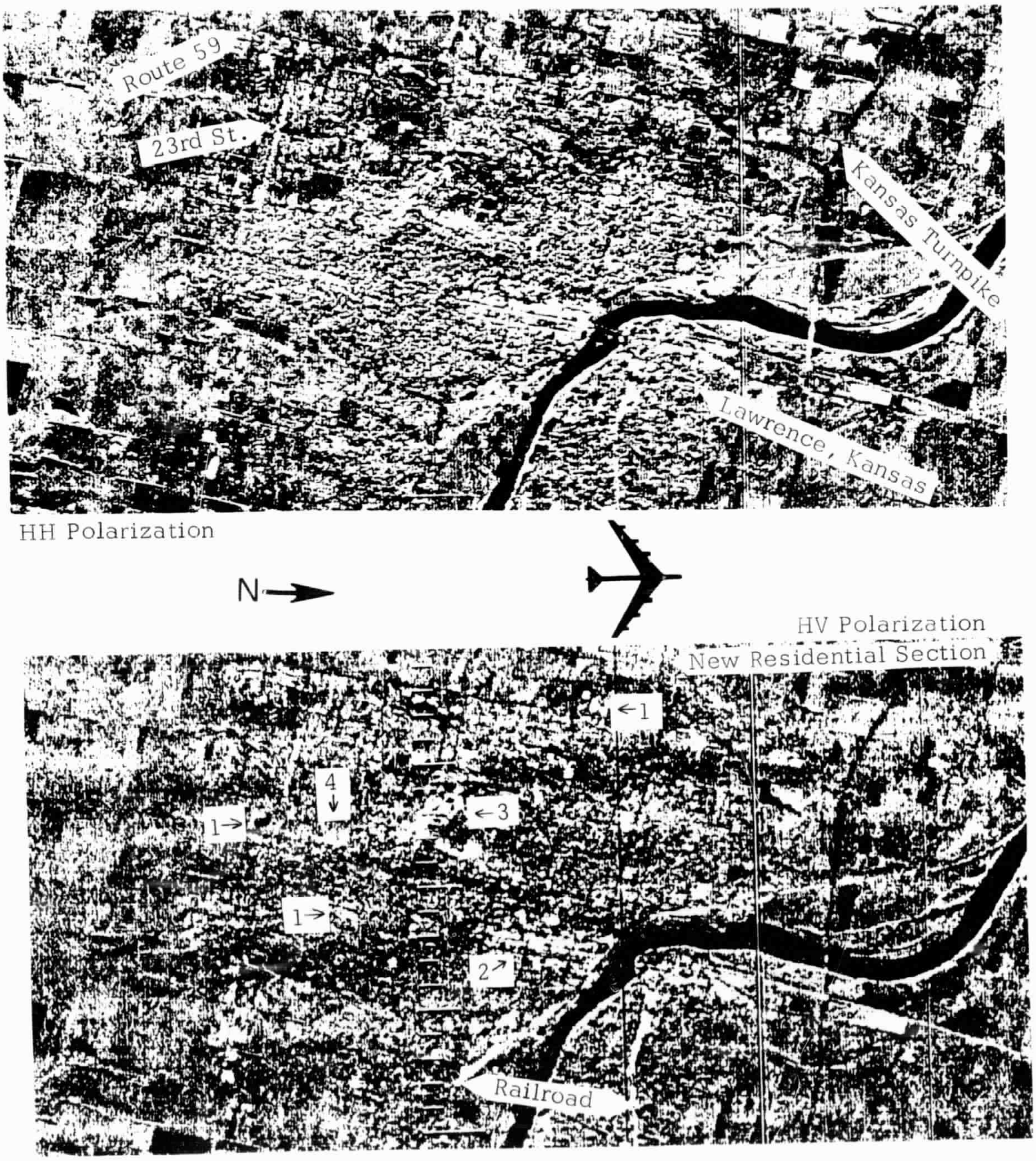

FIGURE 3. MULTIPLE POLARIZATION, K-BAND POSITIVE RADAR IMAGERY OF LAWRENCE, KANSAS

1. Shopping Centers
2. Central Business District
3. University of Kansas
4. Lawrence High School

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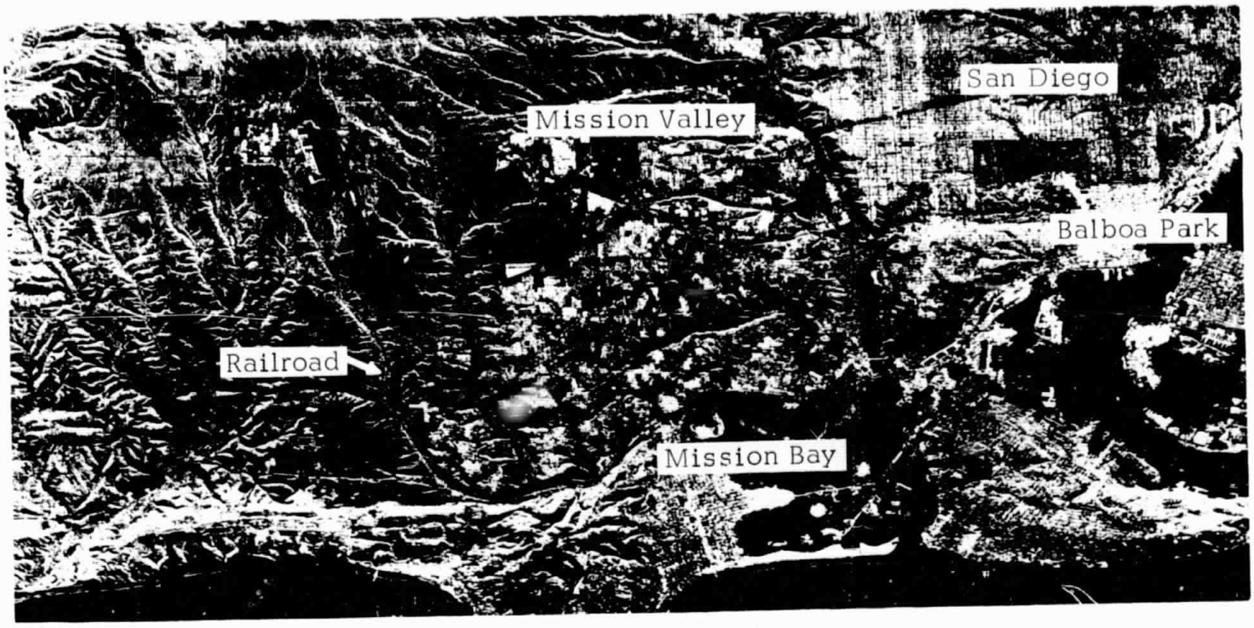
polarized imagery because each target exhibits variations in ability to depolarize the signal. K-band radar imagery of Lawrence, Kansas (Figure 3) and San Diego, California (Figure 4) illustrate the additional information acquired by obtaining both cross- and like-polarized imagery. Several shopping centers of Lawrence, Kansas are more distinguishable on the cross-polarized imagery as is the University of Kansas campus, and Lawrence High School. The slight increase in return on the cross-polarized image west of Route 59 indicates the location of recently developed residential sections. East of Lawrence on 23rd street a high intensity area appears on the like-polarized image but not on the cross-polarized image. Field investigation revealed this area to be a trailer park. The reason for this phenomenon is not clearly understood; however, the alignment of the individual trailers parallel to the flight path may in part be an explanation. The effect of target alignment to the flight path is considered later in more detail.

The effect of building materials and the amount of natural vegetation can be readily seen on both like- and cross-polarized radar images of a portion of San Diego (Figure 4). For example, Balboa Park is easily distinguished from the surrounding residential area on the like-polarized image; however, the two areas are hardly discernable from each other on the cross-polarized image. This is illustrated by the higher positive detection of the park on the like-polarized image, 79.0% detection for interpreters viewing the HH image to 15.7% detection for the HV image, based on the observations of 68 students. (See Table 6). The variance ratio tested to be significant at the .001 level (see Table 7), and therefore the null hypothesis can be rejected at a high level of confidence. Since the residential section surrounding Balboa Park constitutes some of the older residential sections in San Diego, the inability to discriminate the two on the cross-polarized image is in part explained by the abundance of vegetation in both areas. The effect of vegetation can also be noted by comparing the newer, less tree-sheltered residential



HH Polarization

HV Polarization

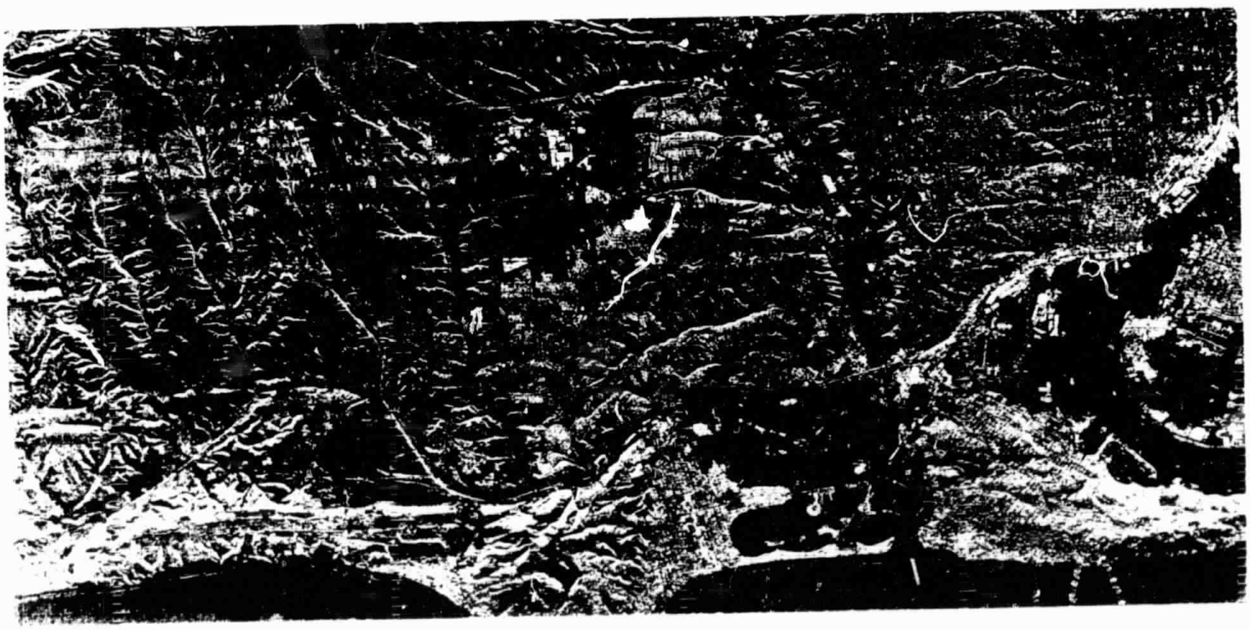


FIGURE 4. SEPARATION OF RESIDENTIAL, PARK AND BUSINESS AREAS USING TWO RADAR POLARIZATIONS, SAN DIEGO, CALIFORNIA

areas north of Mission Valley with the older residential area near Balboa Park (see Figure 4). The former area can be subdivided into two distinct categories on the cross-polarized image, each of which is characterized by roof tops of a particular material. Roofs covered with crushed dolomite predominate in the northwest residential section, whereas shingled roofs and larger buildings are prevalent in the northeast residential section.

The detection of airports, oil tank farms, an oil refinery, an oil field, and a small town on the two polarizations was also tested by the 68 student interpreters. Their findings indicate that except for the detection of a single town outside of Wichita, Kansas (see Figure 7) neither polarization was better on a statistical basis for the delineation of the targets in question. The percentage of airports detected on radar imagery of San Diego, California was 45.6% on the like-polarized imagery and 44.0% on the cross-polarized imagery (see Table 8). The low F value (see Table 9) from the data is indicative of the absence of additional distinguishing characteristics on either polarization. In Superior, Wisconsin, 47% of the interpreters with like-polarized imagery detected the small rural one-runway airport, whereas only 25% of those with cross-polarized imagery detected the runway (see Table 10). The _F_ value in this case is high enough to suspect a reasonable variation between polarizations although the difference is not statistically significant (see Table 11). The conclusion drawn from the data on detection of airports suggests that certain sizes and types of airports may be more easily delineated on a specific polarization. More testing needs to be done before this hypothesis is verified. A _F_ value of 5.15 for the positive detection of a single town is not interpreted to be significant on the basis of the premises that detection was largely by chance as indicated by the extremely low positive to false-positive detection ratio. It is suggested, therefore, that a larger sample be accrued before any conclusions are made (see Tables 12 and 13). Lack of statistical significance between polarizations in the delineating of tank farms, oil refineries, and oil fields is interpreted as indicating that neither polarization was better for interpreting the above cultural features (see Tables 14 through 19). However, the possibility exists that a major source of variation was not included in the error term or that more testing needs to be done.

Transportation and Communication Nets

Detecting the tracing communication nets is performed more easily, completely, and accurately on cross-polarized imagery when the communication net traverses land and is at an angle to the flight path; communication nets either parallel to the flight path or crossing water bodies are more easily observed on like-polarized imagery. Multiple polarized radar imagery of Bountiful, Utah (Figure 5) has been included solely to demonstrate the ability of cross-polarized imagery to detect communication nets.

The effect of alignment in relation to the flight path is demonstrated on the HH and HV radar images near Bountiful, Utah (Figure 5), where A, B, and C indicate increased return from powerlines and railroad tracks parallel to the flight path on like-polarized imagery and D, E, and F illustrate the increased detectability on cross-polarized imagery of transportation and communication nets at an angle to the flight path. Evaluation of the Bountiful, Utah imagery by 68 student interpreters showed that 76.0% of the powerlines and railroad tracks parallel to the flight path were detected on the like-polarized image, whereas only 18.2% were detected on the cross-polarized image (see Table 20). The 18.2% seems high until one considers that the entire percentage detected by the interpreters with cross-polarized imagery represents one parallel segment of the transportation-communication net connecting two other segments oriented at an angle to the flight path and therefore the parallel segment may have been inferred by the appearance of the two unconnected communication lines (see powerline E on Figure 5). The ratio of variance, $\underline{F}$ demonstrates the difference between

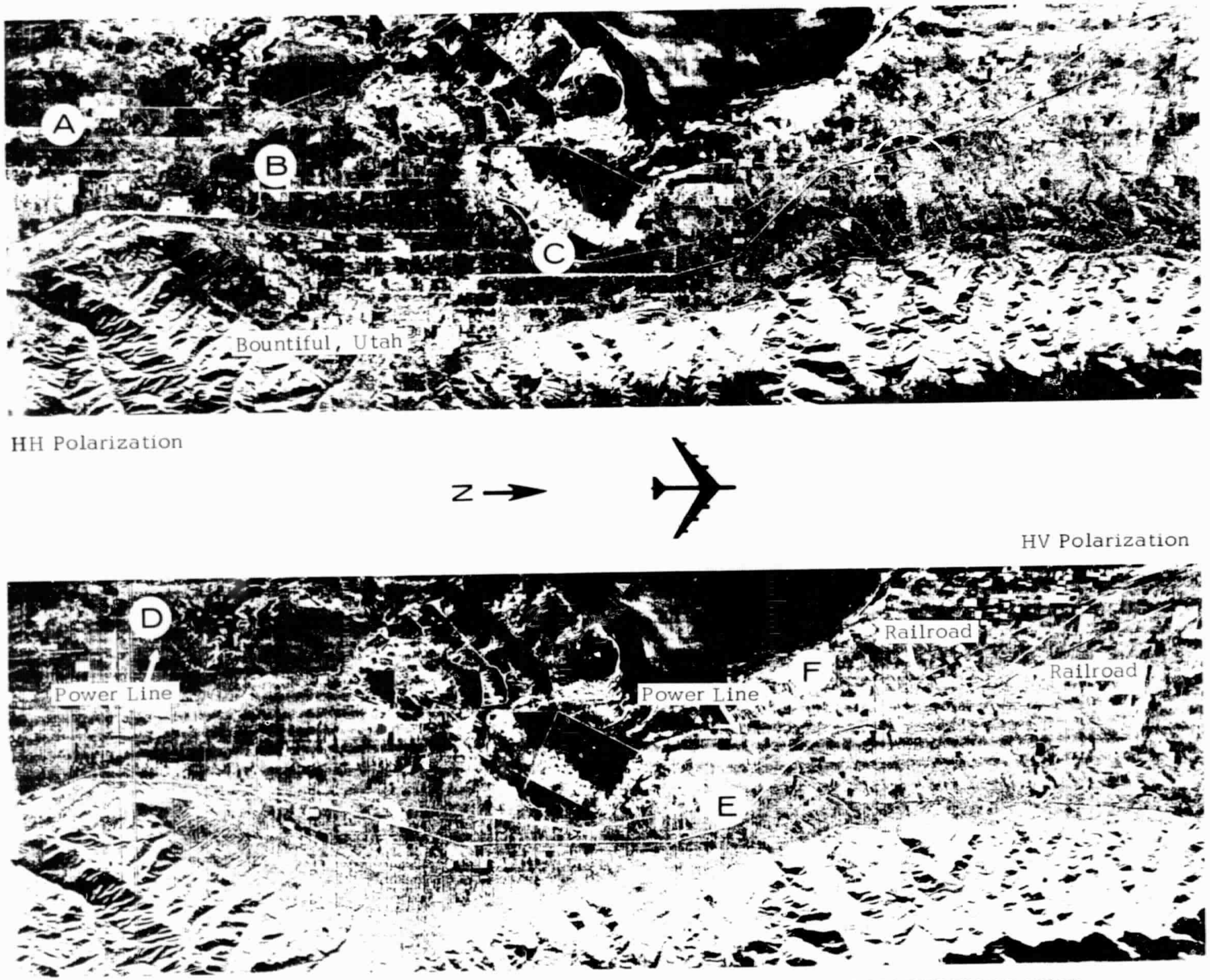


FIGURE 5. DETECTION OF RAIL AND POWER LINES USING TWO RADAR POLARIZATIONS NEAR BOUNTIFUL, UTAH.

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polarizations in detecting transportation and communication lines parallel to the flight path to be extremely significant, $p < .001$ (see Table 21). The delineation of powerlines oriented at an angle to the flight path in Bountiful, Utah was better on the cross-polarized image, 50.5% than on the like-polarized image, 3.5% as shown in Table 22, the difference between the two polarizations in detecting power lines at an angle to the flight path tested to be extremely significant on a statistical basis (see Table 23).

The delineation of transportation arteries, railroads or roads, or both, appears to be influenced by the quality of the image, the geographic area, and the interpreter. This is indicated by the results of testing inexperienced interpreters in detection of transportation arteries on multiple-polarized radar imagery of Superior, Wisconsin (Figure 6) and Wichita, Kansas (Figure 7). The cross-polarization image was judged better for detecting total transportation in the former geographic area (see Table 24), whereas the like-polarized image was judged better at Superior, Wisconsin (see Table 26). Both of the above were tested to be significant at the .05 level of confidence (see Tables 25 and 27). Detection of road and railroads on both the like- and cross-polarized radar images of Whichita, Kansas, and Superior, Wisconsin range from 40 to 60%. Both A and B on Figure 8 demonstrate the variation between polarizations in the detection of transportation arteries near Banida, Idaha. Although this report is concerned with cultural features, it is interesting to point out the difference in return from the dry stream bed at C on the like- and cross-polarized image as well as the signature from agricultural land north of A.

Identification of roads varied by only one percent between polarizations of Wichita, Kansas, 28.0% on the like-polarized image to 27.0% on the cross-polarized image (see Table 28). The ratio of variance, .03, was not large enough to be statistically significant (see Table 29). These results suggest that in Wichita, Kansas, the difference between

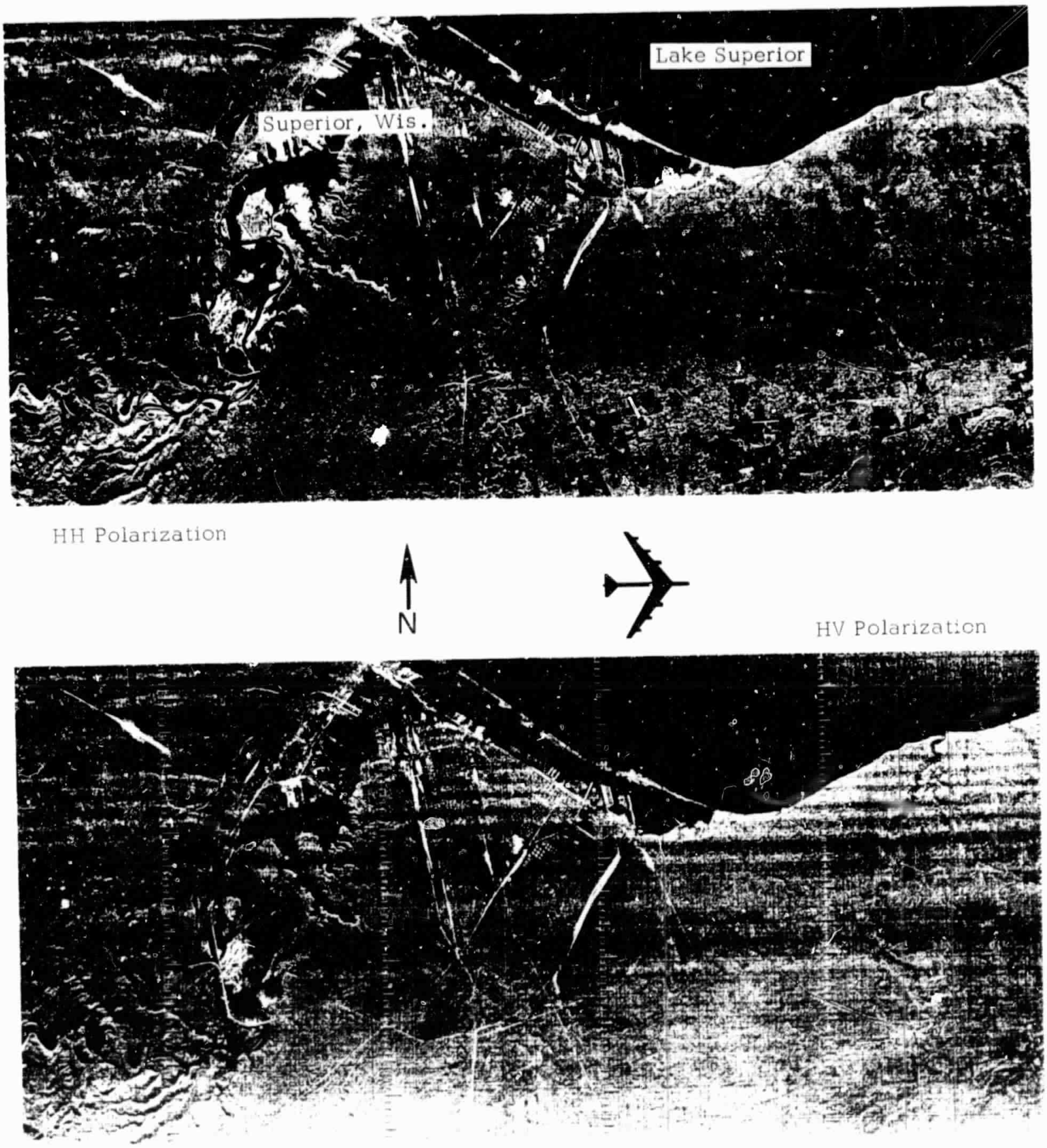

FIGURE 6. DETECTION OF TRANSPORTATION ROUTES AND INDUSTRIAL SITES USING TWO RADAR POLARIZATIONS, SUPERIOR, WISCONSIN.

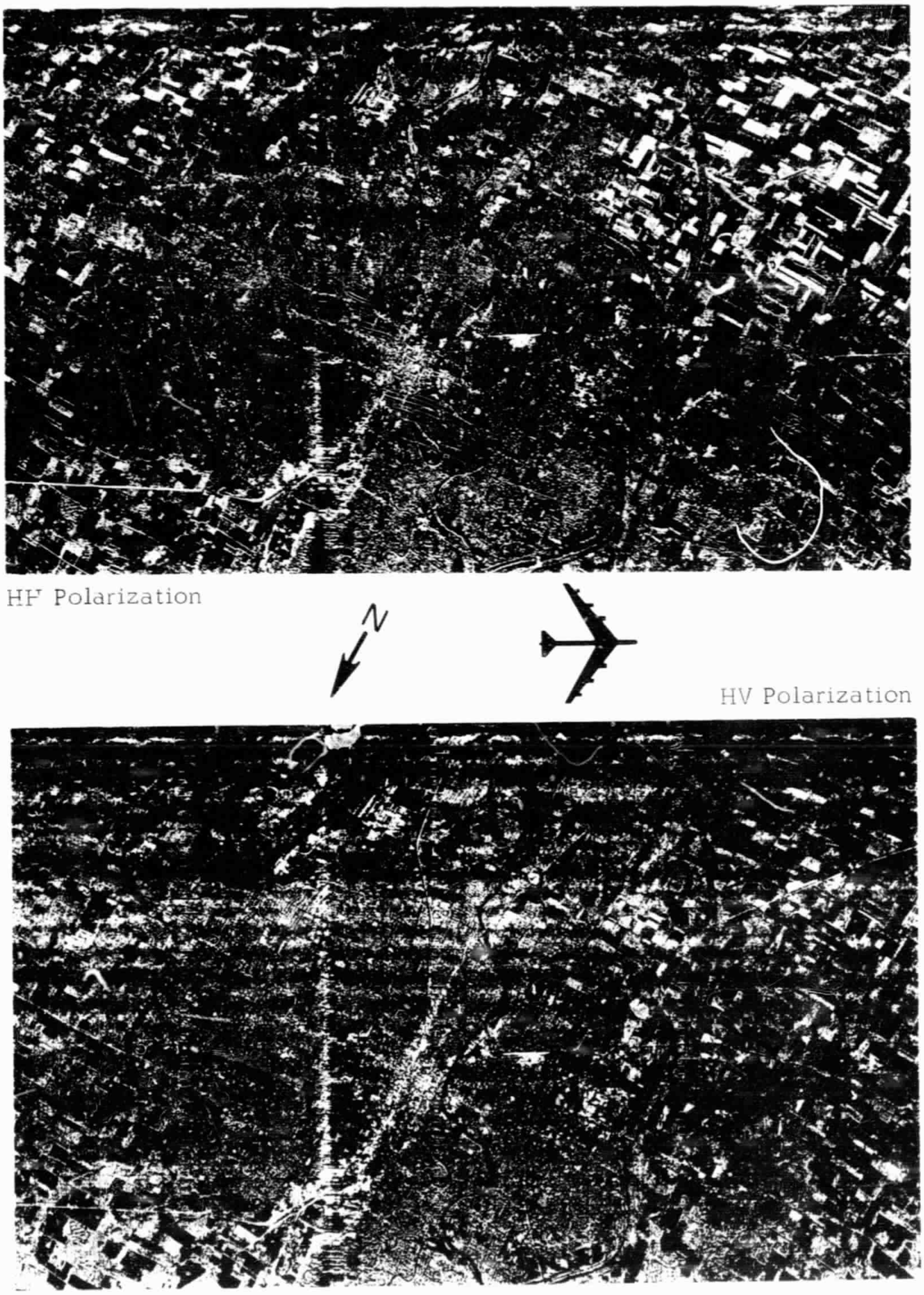

FIGURE 7. DETECTION OF BRIDGES ACROSS THE ARKANSAS RIVER WITH TWO RADAR POLARIZATIONS, WICHITA, KANSAS

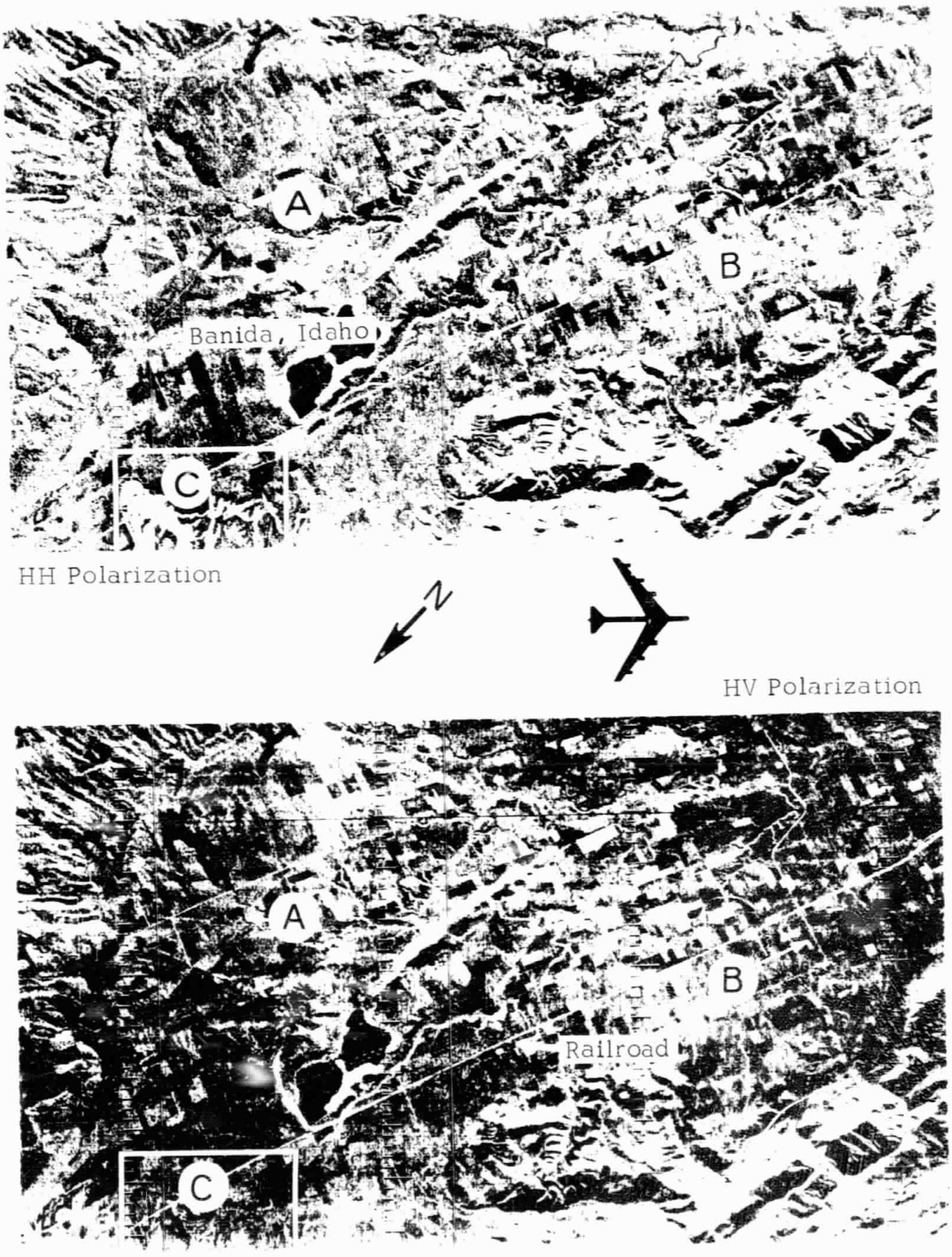

FIGURE 8. DETECTION OF TRANSPORTATION ROUTES USING TWO POLARIZATIONS NEAR BANIDA, IDAHO

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polarizations is not significant for detecting roads, although it is possible that a major source of variation was omitted in the error term. In Superior, the difference in the ability of the polarizations for detecting roads was tested to be extremely significant, .001 level of confidence (see Table 31), as the percent detected varied from 50.5 on the HH or like-polarization to 22.4 on the HV or cross-polarization (see Table 30). The low radar return characteristic of roads in relation to railroads does not lend itself to a high number of false-positive detections. The total detection of roads, including those detected falsely as railroads, followed the same pattern exemplified by positive detection of roads, i.e., the percentage detected in Wichita was higher on the like-polarization but the data did not prove to be significant at the .05 level of confidence whereas, in Superior, Wisconsin the data proved to be extremely significant with the like-polarized image interpreters detecting 54% on the like-polarized and only 20.3% on the cross-polarized imagery (see Tables 32 - 35).

Railroads were more completely delineated on radar than were roads, although false-positive detection (railroads marked as roads) was greater. False-positive detection of roads as railroads, mentioned previously, is very low which in part is accounted for because railroads give more radar return than roads. Positive detection of railroads in Wichita, Kansas and Superior, Wisconsin deviated less than $\pm$ 5% around 50% for either polarization. In Wichita, Kansas the greater percentage was detected on the cross-polarized image, 54.2% in relation to 45.4% on the like-polarized image (see Table 36). The $\underline{F}$ test showed that this data was significant at a .001 level of confidence with a $\underline{F} = 12.22$ (see Table 37). It can be concluded, therefore, that in Wichita the HV, cross-polarized radar image, was better for the detection of railroads than the HH, like-polarized radar image. The conclusion cannot be carried over and applied to the radar imagery of Superior, Wisconsin where the interpretation on the like- and cross-polarization did not differ significantly (see Tables 35 and 39). The $\underline{F}$ of .32 was far below the level needed to reject the null hypothesis at the .05 level of confidence. The percentage of railroads detected, whether marked as railroads or roads, was greater on the cross-polarized images of both geographic areas (see Tables 40 and 42) although only the data from Wichita, Kansas tested to be extremely significant, .001 level of confidence (see Tables 41 and 43).

Detection of transportation and communication nets that traverse water bodies (bridges and powerlines) was more complete with like-polarized imagery in Wichita, Kansas (see Figure 7) and in San Diego, California (see Figure 4). Of the 22 bridges across the Arkansas River in the Wichita, Kansas area encompassed by radar imagery, an average of 15.7 (78.8%) were detected by the 36 student interpreters viewing those like-polarized imagery while only 6.2 (31.0%) were detected by those with cross-polarized imagery (see Table 44). The difference in the detection of bridges is significant at P = .001 (see Table 45). A positive to false-positive ratio of 566 to 1 on like-polarized imagery indicates the high degree of positive identification associated with bridge detection. The ratio on cross-polarized imagery was lower, 18 to 1. Several of the false-positive detections on both images were range marks on the image that had been mistaken for bridges, a mistake not likely to be made by an experienced interpreter. The Kansas Turnpike bridge over the Kansas River (see Figure 3) illustrates the more pronounced radar return on the like-polarized imagery of a transportation artery traversing a water body.

Forty-eight percent of the channel markers traversing San Diego Bay were detected by the interpreters using the like-polarization, and only 5.8% by those with the cross-polarized image (see Table 46). As with the detection of bridges, the statistics proved to be significant at P = .001 (see Table 47). The ratio of positive to false-positive detection, though low, on the like-polarized (3.3 to 1) was at least positive, whereas on the cross-polarized image there were more false than correct identifications (0.35 to 1) (see Table 46).

Agricultural Patterns

Variations in intensity of return are also found on the like- and cross-polarized imagery of agricultural areas. These variations, which reflect differences in crop types and/or field conditions, provide the interpreter with additional information not available prior to the use of multiple polarized radar imagery. Near Thurmont, Maryland (Figure 9) dark fields on the cross-image immediately attract one's attention; however, more subtle gray value differences between the like- and cross-polarized images are visible at B, C, and D. Detection of field A was enhanced on cross-polarized imagery; whereas field B is more predominant on the like-polarized image. Areas C and D illustrate some of the changes in relative gray tone values associated with like- and cross-polarized imagery and should dispel the belief that the additional information on the cross-polarized image is only a result of lifting the noise level. In some areas, such as near Monticello, Utah (see Figure 10) where land-use is limited primarily to grazing, the cross-polarized image appears to be better for the delimitation of field boundaries. Areas A and B on Figure 10 illustrate the greater detectability of field boundaries on the cross-polarized image than on the like-polarized image.

Statistical Summary

The studies involving detection of spots of high intensity provided the following ranking of polarizations: 1. HV - Highest detection capability, 2. HH and VH - Intermediate detection capability, and 3. VV - Lowest detection capability.

Statistical analysis of the student interpretation employing HH and HV imagery revealed the following:

1. At the 99.9% confidence level
    a) the like-polarized (HH) imagery was better for detecting vegetated residential areas and parks versus non-vegetated urban areas; power lines and railroads when aligned parallel to the flight path or crossing water bodies; and bridges and channel markers.

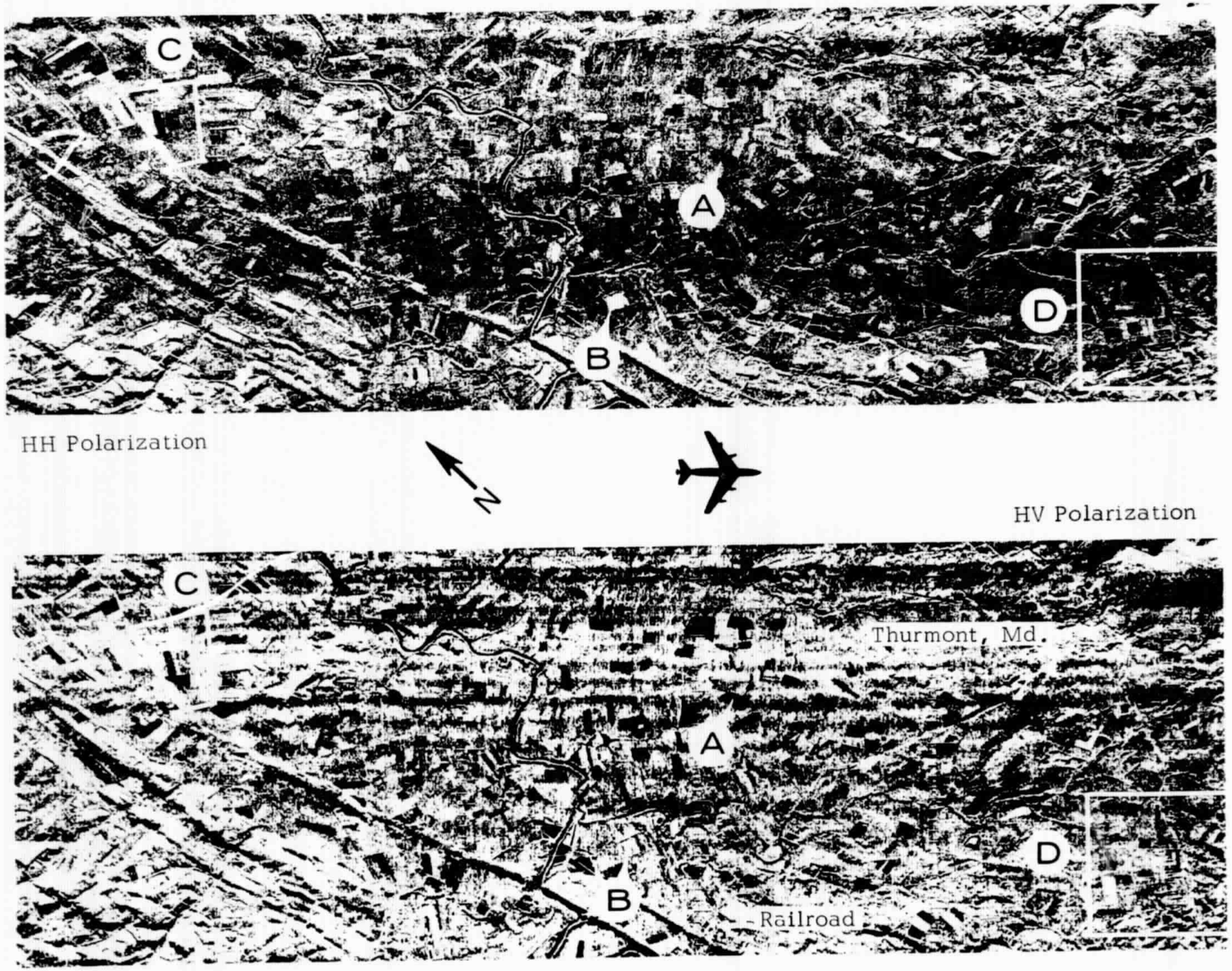

FIGURE 9. AGRICULTURAL PATTERNS DETECTED BY TWO RADAR POLARIZATIONS IN THE VICINITY OF THURMONT, MARYLAND.

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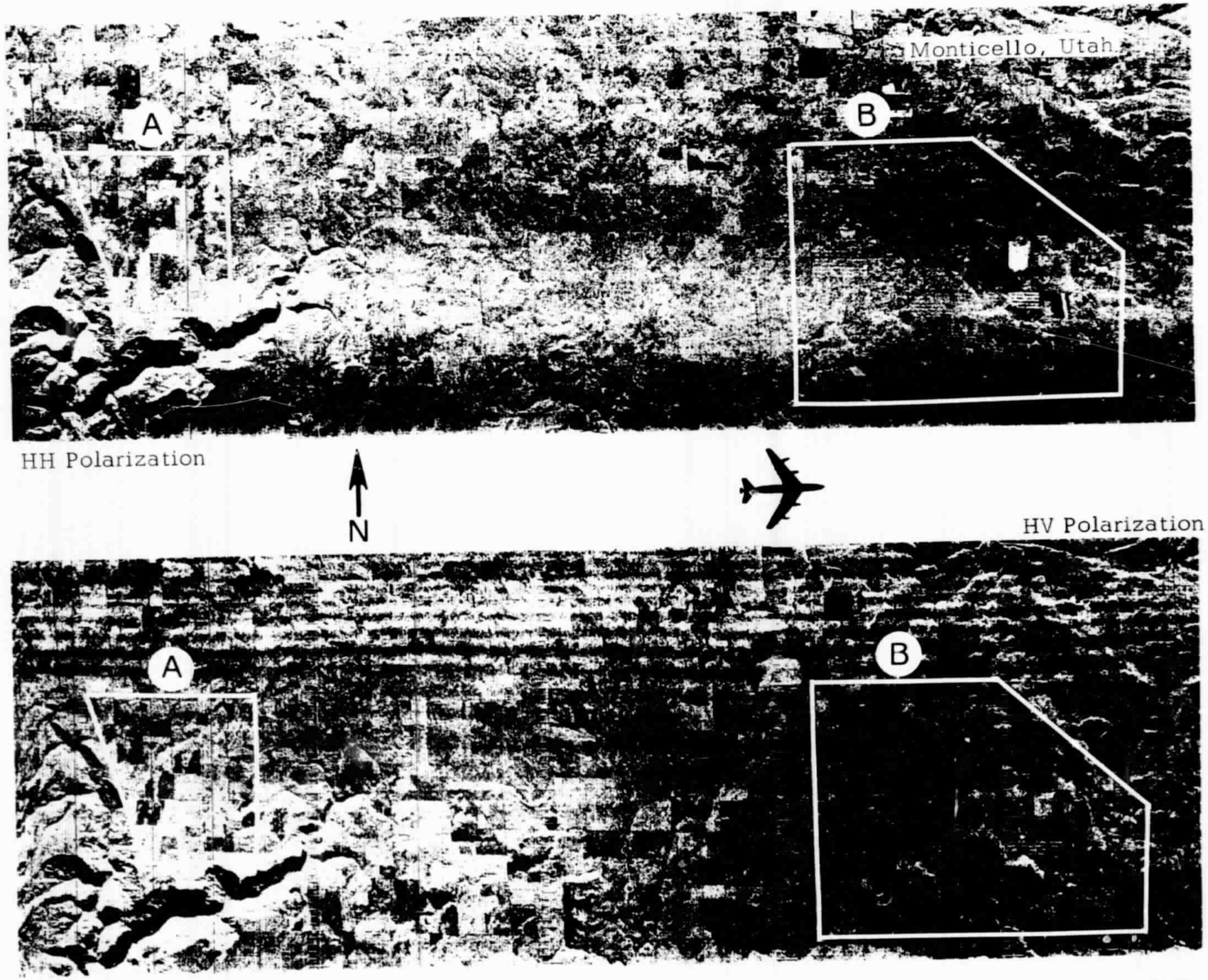

FIGURE 10. DETECTION OF PASTURE AND CULTIVATED LANDS USING TWO RADAR POLARIZATIONS NEAR MONTICELLO, UTAH.

b) the cross-polarized (HV) imagery was better for detecting powerlines and railroads when at an angle (other than parallel) to the flight path or traversing land.

2. At the 95% confidence level the like-polarized imagery was better for detecting the central business district (CBD).
3. Detection of airports and roads did not prove to be significantly different on either the HH or HV polarizations.
4. Cross-polarized radar imagery was better for detecting railroad nets, however, the degree of confidence varied from 99.9% to less than 95% depending on the area studied.

SUMMARY

A summary of the results comparing two polarizations received simultaneously on one pass, HH to HV or VV to VH, is as follows:

1. The HH Polarization in general proved better for
   a) delineation of vegetated areas within an urban complex, such as, Balboa Park in San Diego, or the Golden Gate Park in San Francisco
   b) detection of transportation and communication arteries that traverse water bodies; and
   c) detection of communication lines oriented parallel to the flight path.
2. The HV Polarization in general was better for
   a) detection of buildings in a rural setting, as well as shopping centers, industrial and manufacturing plants, and other cultural conglomerations that produce a high orthogonally depolarized signal; and
   b) detection of communication lines oriented at an angle other than parallel.
3. Variations between VV and VH imagery were only tested in the detection of buildings where it was found that VH imagery was better than VV.

A decisive conclusion is not warranted for evaluating polarization schemes in the detection of transportation lines without further investigation. Other parameters--quality of image, the geographic area, and experience of the interpreter--along with polarization variations should be included in future testing. Visual observations, however, suggest that railroads are more completely detectable on the cross-polarized image whereas no one polarization is better for detection of roads.

Detection of airports larger than one runway was not enhanced by any polarization scheme, however, the variation experienced in the interpretation of a single runway airport in a rural setting was large enough to suggest

increased detectability on the like-polarized imagery.

Variations between like- and cross-polarized radar imagery were visible in agricultural areas, suggesting differences in crop types and/or field conditions. The lack of ground data prohibited determination of the cause-effect relationship and will until such data are collected at the time of overpass.

CONCLUSION

Multiple polarized radar imagery provides the geoscientist with information relating to the complex physical properties of the target not otherwise available with a single polarized system. More specifically several of the applications in the sensing of cultural features are as follows:

1) Helping to discriminate between residential and business or industrial districts,
2) Increasing the ability to plot more complete transportation and communication nets,
3) Providing the observer with additional information concerning the rural setting or location and number of farmsteads, and
4) Separating fields of different crops or crop states.

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BIBLIOGRAPHY

Dellwig, L. F. and R. K. Moore (1966): "The Geologic Value of Simultaneously Produced Like- and Cross-Polarized Radar Imagery," Journal of Geophysical Research, Vol. 71, No. 14, pp. 3597-3601. Also published as CRES Report 61-13, University of Kansas.

Ellermeier, R. D., A. K. Fung, and D. S. Simonett (1966): "Empirical and Theoretical Interpretation of Multiple Polarization Radar Data in the Geosciences," Fourth Symposium on Remote Sensing of the Environment, University of Michigan, Ann Arbor, Michigan, April 11-14, 1966.

Fung, A. K. (1966): "Scattering and Depolarization of Electromagnetic Waves by Rough Surfaces," CRES Report 48-5, University of Kansas.

Gillerman, E. (1967): "Investigation of Cross-Polarized Radar on Volcanic Rocks," CRES Report 61-25, University of Kansas.

Lewis, A. J. (1966a): "Comparison of Like- and Cross-Polarized Radar Imagery by Counting Spots of High Intensity Return," Unpublished CRES Memorandum.

Lewis, A. J. (1966b): "Summary of Observations on Like, Cross, and Difference Radar Imagery," Unpublished CRES Memorandum.

Morain, S. A. (1967): "Field Studies on Vegetation at Horsefly Mountain, Oregon and Its Relation to Radar Imagery," CRES Report 61-22, University of Kansas.

Morain, S. A. and A. J. Lewis (1966): "Interpretation of Multiple-Polarized K-band Radar Imagery," Unpublished CRES Memorandum.

Morain, S. A. and D. S. Simonett (1966): "Vegetation Analysis with Radar Imagery," Fourth Symposium on Remote Sensing of the Environment, University of Michigan, Ann Arbor, Michigan, April 11-14, 1966. Also published as CRES Report No. 61-9, University of Kansas.

Morain, S. A. and D. S. Simonett (1967): "K-Band Radar in Vegetation Mapping," Photogrammetric Engineering, Vol. 33, No. 7, pp. 730-750. Also published as CRES Report 61-23, University of Kansas.

APPENDIX I

Name ______________________________

Age _________

Year in school ____________________________

	Yes	No
Previous experience with radar imagery...	___	___

If yes specify:

Knowledge of the following areas...	Yes	No
1. Bountiful, Utah	___	___

If yes specify:

2. San Diego, California	___	___

If yes specify:

3. Superior, Wisconsin	___	___

If yes specify:

4. Wichita, Kansas	___	___

If yes specify:

INTERPRETATION OF CULTURAL FEATURES ON MULTI-POLARIZED RADAR IMAGERY OF CULTURAL FEATURES

Introduction

(U) Radar (Radio Detecting and Ranging) has been employed by the military since the 1940's for the location (both distance and direction) of targets. Nonmilitary uses such as for the tracking of tornadoes and hurricans developed as an outgrowth of the military uses. The ability of near all-weather, 24-hour sensing capabilities has made radar a useful tool for scanning terrain, both terrestrial and extra-terrestrial.

(U) Presently, under NASA contract, the Center for Research in Engineering Science (CRES) is evaluating the geoscience potential of radar imagery. One facet of this study involves the detectability of cultural features on radar imagery of different polarizations.

(U) The purpose of this experiment is to test the ability of interpreters with little or no previous knowledge of radar interpretation in the detection of cultural objects. In this report the cultural objects are limited to roads, railroads, airfields, bridges, powerlines, industrial centers, residential and urban areas, oil fields, and open pit mines.

Identifying Characteristics of Cultural Features on Radar Imagery

Roads and Railroads

(U) Transportation lines can be detected by the linearity of the return and the connection of two areas of industrial or commercial activity. Railroads are more distinguishable than are roads because of a higher return (brighter line).

Airfields

(U) Airfields are distinguishable primarily by the characteristic shape of the runways which give a low return, appearing dark on the radar imagery. A rough categorization of size can be made by the size of the runways and the cargo and passenger terminal.

Bridges

(U) Generally bridges produce a higher return than transportation routes due in part to the difference in building material and geometric shape. The overall length of a bridge is such that on radar imagery it appears as a short bright line segment.

Powerlines

(U) Powerlines show up on radar imagery as spots of high intensity return (bright spots) aligned along a straight path. The distance between the spots gives indication of the maximum voltage that can be transported through the wire.

Residential and Urban Areas

(U) These sections generally show up as areas of high intensity return, the size of which can be used to estimate the population of the city, at least in terms of degree of magnitude. Within the boundaries of the urban complex a further subdivision may be made on the basis of relative return and location. The center business district (CBD) can be detected by a very high return produced by the collection of large commercial buildings. The central business district does not necessarily have to be located at the geometric center of the urban complex but is generally found where the city was first established. Residential areas produce a lower return than the central business district due to the presence of more natural vegetation. A further sub-division of residential areas by age is possible as the older residential areas have more natural vegetation than the newer sections and therefore have a lower return. Industrial areas are characterized by high return and may be inseparable if juxtaposed with the central business district. The location near a heavy concentration of railroad tracks or along the banks of a water body also help to locate industrial areas. Small industrial plants and shopping centers outside of the CBD are usually only detected if the interpreter is familiar with the area covered by the radar image. Both the industrial plant and shopping center produce a high return which varies from dot size if it is only a single building, to a much larger area when the target consists of several closely spaced buildings.

(U) Within the city limits low return areas usually of block size or more indicates the position of an area predominantly covered by natural vegetation such as a park, or institutional grounds. Institutional grounds, such as the campus of Kansas University, can be distinguished from the park by the presence of large buildings on the grounds.

Mining Activities

(U) Oil wells, both on and off-shore, can be located and counted on radar imagery. They produce spots of high return on radar imagery and are distinguished from powerlines by their random arrangement in what are known to be oil producing fields.

(U) The position of a slag pile adjacent to a depression indicates the presence of an open-pit mine or quarry, which if partially filled with water suggests that operations have been discontinued and the quarry abandoned. Large operations generally have rail-lines leading to or from the mine with rail cars, steam shovels, and other earth-moving vehicles producing high return spots in the quarry.

Water Bodies

(U) A brief introduction to the presentation of water bodies on radar imagery is important even though this exercise is not directly concerned with their detection. Water bodies such as, lakes and rivers, are distinguished by low return and are presented on radar imagery as dark areas. Large rivers, for example the Kansas River, appears as a dark band which frequently meanders across the image. Smaller rivers or streams generally stand out because of tall, dense vegetation along the banks which produce a higher return than the surrounding vegetation. Still water bodies such as reservoirs, lakes, and ponds are dark areas distinguishable by size and shape. Still water bodies comparable in size to a cultivated field are difficult to separate from certain field crops which give a low return however, a distinction can be made on the basis of shape since fields are generally rectangular in shape and ponds are circular.

DIRECTIONS

(U) Four sites have been prepared for this exercise. The prints that you will be using are positive radar images of the following geographic locations:

1. Bountiful, Utah
2. San Diego, California
3. Superior, Wisconsin
4. Wichita, Kansas

On each image you will be asked to locate certain cultural objects marking your selection on the acetate overlay with the appropriate symbol found on the accompanying sheet of symbols. Each site carries separate instructions as to what cultural object you are to locate and special directions when necessary. Do not designate any cultural object not asked for in the instructions. If the designation of a cultural object is difficult due to limited space, outline the area and place the appropriate symbol near the area connected by an arrow.

(U) Please do not start until given the signal and stop when asked.

<u>Site 1</u>

Location: Bountiful, Utah
Scale: 1 inch = 2.6 miles
Time: 10 minutes
Cultural object: Power Transmission Lines

<u>Site 2</u>

Location: San Diego, California
Scale: 1 inch = 3.75 miles
Time: 10 minutes
Cultural objects: Airports
City Park
Power Transmission Lines over Water

Site 3

Location: Superior, Wiconsin (along the SW shoreline of Lake Superior)

Scale: 1 inch = 3.3 miles

Time: 20 minutes

Cultural objects: Tank Farms - Count the individual tanks placing the total number within the outlined boundary

Railroads - Indicate multiple tracks as well as single tracks

Major Roads

Airport - locate only one

Oil Refinery - Use knowledge of cultural objects already located. Indicate by the symbol

Site 4

Location: Wichita, Kansas

Scale: 1 inch = 2.5 miles

Time: 20 minutes

Cultural objects: Bridges over the Arkansas River

Central Business District

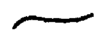
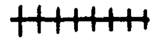
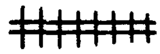
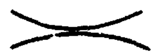
Oil Fields

Towns outside of Wichita, Kansas

Railroads

Major Roads

SYMBOLS

Cultural Object	Symbol
Road	
Railroad	
Single Track	
Multiple Track	
Airport	
Power Transmission Line	
Bridge	
Urban Area	
Residential	
Commercial/Industrial	
Central Business District	
Village/Town	
City Parks	
Oil Field	
Oil Wells	
Tank Farm (Oil Tanks)	
Oil Tanks	
Open Pit Mine or Quarry	

APPENDIX II

Table 1

Individual Results of Comparison of Like- and Cross-Polarized Radar Imagery by Counting Spots of High Intensity Return

Interpreter	Area A Polarization HH	HV	Interpreter	Area B Polarization HH	HV
1	43	70	1	154	128
2	26	67	2	88	97
3	27	54	3	65	83
4	29	66	4	58	86
5	48	70	5	58	92
6	65	84	6	58	104
Total	238	411		481	590
Average	39	68		80	98
Standard Deviation	11.3	8.8		34.2	14.5
Ratio of HV/HH	1.75			1.25	

Interpreter	Area C Polarization VV	VH	Interpreter	Area D Polarization VV	VH
1	98	118	1	41	65
2	64	83	2	19	47
3	115	122	3	36	72
4	69	107	4	29	63
5	74	98	5	34	53
6	82	120	6	41	78
Total	502	648		200	378
Average	83	109		33	63
Standard Deviation	17.2	13.9		7.6	10.5
Ratio of VH/VV	1.34			1.9	

Table 2

Percentage of Buildings According to Building Material and Roof Direction That Are Detectable by Multipolarized Radar Imagery.[1]

Polarization	Building Material				Roof direction in relation to North				
	Metal	Composition	Slate	Asphalt					
HH only	1.4	0.0	0.0	0.0	0.0	0.0	2.0	0.0	1.1
HV only	5.6	3.2	0.0	0.0	3.0	40.0	6.0	0.0	3.4
VV only	4.6	8.1	0.0	0.0	4.1	0.0	8.0	0.0	3.4
VH only	10.2	9.7	0.0	0.0	5.1	20.0	15.0	0 0	9.1
Total on single polarization	21.8	21.0	0.0	0.0	12.2	60.0	34.0	0.0	17.0
Detected on more than one polarization	44.7	22.6	40.0	100.0	51.0	0.0	35.0	0.0	36.4
Total Detected	66.7	43.5	40.0	100.0	63.3	60.0	69.0	0.0	53.4
Not detected on any polarization	33.3	56.5	60.0	0.0	36.7	40.0	31.0	100.0	46.6
Total Targets	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

1. Flight path was NW-SE

Table 3

Percentage of Buildings Detected on Each Polarization According to Roof Material--Roof Direction Combinations[1,2]

Roof Material and Direction	Polarization HH	HV	VV	VH	Total % Detected At Least One Polarization	Total Number Possible
M-N	34	35	37	50	63	86
M-NE	0	50	0	0	50	4
M-E	35	42	31	58	82	71
M-NW	0	0	0	0	0	2
M-C	25	28	28	52	59	69
Co-N	6	31	31	31	44	16
Co-NE	0	0	0	0	0	0
Co-E	9	9	19	16	44	32
Co-NW	0	0	0	0	0	0
Co-C	8	8	15	23	39	13
SL-N	0	0	0	0	0	0
SL-NE	0	0	0	0	0	0
SL-E	0	0	0	0	0	2
SL-NW	0	0	0	0	0	0
SL-C	22	22	22	33	55	9

1. Flight path was NW-SE
2. Legend

   M = Metal

   Co = Composition

   SL = Slate

   N = North-South

   NE = Northeast-Southwest

   E = East-West

   NW = Northwest-Southeast

   C = Complex

Table 4 Detection of Central Business District in Wichita, Kansas	Polarization	
	HH	HV
Number of Interpreters	36	32
Total Positive Detection	35	27
Average Positive Detection	0.97	0.84
Precent Positive Detection	97.20	84.50
Total False Positive Detection	7	7
Ratio Positive/False Positive Detection	5 to 1	3.86 to 1

Table 5

Analysis of Variance of Total Positive Detection of Central Business District, Wichita, Kansas

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Sq. Variance	Ratio of Variances, F
Total	548	67		
Between Region	28	1	.28	4.00
Within Region	520	66	.07	

$P(F_{1,67} = 4.00) = .05$

Table 6 Detection of Balboa Park, San Diego, California	Polarization	
	HH	HV
Number of Interpreters	34	34
Total Positive Detection	27	5
Average Positive Detection	0.79	0.15
Percent Positive Detection	79.00	15.70
Total False Positive Detection	67	65
Ratio Positive/False Positive Detection	.40 to 1	.077 to 1

Table 7

Analysis of Variance of Total Positive Detection of Balboa Park, San Diego, California

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Sq. Variance	Ratio of Variances, F
Total	17.18	67		
Between Region	6.18	1	6.18	38.62
Within Region	11.00	66	.16	

$P(F_{1,67} = 38.62) < .001$

Table 8

Detection of Airports, San Diego, California

	Polarization	
	HH	HV
Number of Interpreters	34	34
Total Positive Detection	64	60
Average Positive Detection	1.84	1.76
Percent Positive Detection	45.60	44.00
Total False Positive Detection	9	6
Ratio Positive/False Positive Detection	7.1 to 1	10 to 1

Table 9

Analysis of Variance of Total Positive Detection of Airports, San Diego, California

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Sq. Variance	Ratio of Variances, F
Total	58.29	67		
Between Region	.10	1	.10	.12
Within Region	56.19	66	.83	

$P(F_{1,67} = .12) > .05$

Table 10

Detection of an Airport, Superior, Wisconsin

	Polarization	
	HH	HV
Number of Interpreters	32	36
Total Positive Detection	15	9
Average Positive Detection	0.47	0.25
Percent Positive Detection	47	47
Total False Positive Detection	11	11
Ratio Positive/False Positive Detection		

Table 11

Analysis of Variance of Total Detection of an Airport, Superior, Wisconsin

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Sq. Variance	Ratio of Variances, F
Total	15.53	67		
Between Region	.81	1	.81	3.68*
Within Region	14.72	66	.22	

$P(F_{1,67} = 3.68) > .05$

*Close to .05 level and is probably significant at .10

Table 12 Detection of a Town, Wichita, Kansas		
	Polarization	
	HH	HV
Number of Interpreters	36	32
Total Positive Detection	6	13
Average Positive Detection	0.16	0.41
Percent Positive Detection	16	41
Total False Positive Detection	75	85
Ratio Positive/False Positive Detection	.08 to 1	.15 to 1

Table 13

Analysis of Variance of Total Positive Detection of a Town, Wichita, Kansas

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Sq. Variance	Ratio of Variances, F
Total	13.70	67		
Between Region	.98	1	.98	5.15
Within Region	12.72	66	.19	

$P(F_{1,67} = 5.15) < .05$

Table 14 Detection of Tank Farms, Superior, Wisconsin		
	Polarization	
	HH	HV
Number of Interpreters	32	36
Total Positive Detection	35	44
Average Positive Detection	0.91	1.20
Percent Positive Detection	46	61
Total False Positive Detection	5	9
Ratio Positive/False Positive Detection	1.4 to 1	2 to 1

Table 15

Analysis of Variance of Total Detection of Tank Farms, Superior, Wisconsin

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Sq. Variance	Ratio of Variances, F
Total	37.23	67	.28	
Between Region	.28	1	.55	.50
Within Region	36.95	66		

$P(F_{1,67} = .50) > .05$

Table 16 Detection of Oil Refineries, Superior, Wisconsin		
	Polarization	
	HH	HV
Number of Interpreters	32	36
Total Positive Detection	23	28
Average Positive Detection	0.72	0.77
Percent Positive Detection	72	77
Total False Positive Detection	7	4
Ratio Positive/False Positive Detection		

Table 17 Analysis of Variance of Total Positive Detection of Oil Refineries, Superior, Wisconsin				
Source of Variation	Sums of Squares	Degrees of Freedom	Mean Sq. Variance	Ratio of Variances, F
Total	13.31	67		
Between Region	.06	1	.06	.30
Within Region	13.25	66	.20	

$P(F_{1,67} = .30) > .05$

Table 18 Detection of Oil Fields in Wichita, Kansas		
	Polarization	
	HH	HV
Number of Interpreters	36	32
Total Positive Detection	3	8
Average Positive Detection	0.08	0.25
Percent Positive Detection		
Total False Positive Detection	42	46
Ratio Positive/False Positive Detection	.07 to 1	.17 to 1

Table 19 Analysis of Variance of Total Positive Detection of Oil Fields, Wichita, Kansas				
Source of Variation	Sums of Squares	Degrees of Freedom	Mean Sq. Variance	Ratio of Variances, F
Total	9.23	67		
Between Region	.28	1	.28	2.15
Within Region	8.95	66	.13	

$P(F_{1,67} = 2.15) > .05$

Table 20

Detection of Power Lines Parallel to Flight Path, Bountiful, Utah

	Polarization HH	Polarization HV
Number of Interpreters	35	33
Total Positive Detection in Inches	72.72	16.7
Average Positive Detection in Inches	1.98	0.50
Percent Positive Detection	76.00	18.20 *
Total False Positive Detection	80	49
Ratio Positive/False Positive Detection	.91 to 1	.34 to 1

*Entire percent is accounted for by detection of one power line that connected power lines at an angle to the flight path.

Table 21

Analysis of Variance of Total Positive Detections of Power Lines in Inches, Bountiful, Utah

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Sq. Variance	Ratio of Variances, F
Total	129.31	67		
Between Region	86.68	1	86.68	135.43
Within Region	42.63	66	.64	

$P(F_{1,67} = 135.43) < .001$

Table 22

Detection of Power Lines Oriented at an Angle to Flight Path, Bountiful, Utah

	Polarization HH	Polarization HV
Number of Interpreters	35	33
Total Positive Detection in Inches	9.98	133.9
Average Positive Detection in Inches	0.28	4.04
Percent Positive Detection	3.50	50.50
Total False Positive Detection	Totaled with the	
Ratio Positive/False Positive Detection	power lines parallel	

Table 23

Analysis of Variance of Total Positive Detections of Power Lines in Inches, Bountiful, Utah

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Sq. Variance	Ratio of Variances, F
Total	29.19	67		
Between Region	19.78	1	19.78	141.2
Within Region	9.41	66	.14	

$P(F_{1,67} = 141.2) < .001$

Table 24

Detection of Total Transportation Lines, Wichita, Kansas

	Polarization HH	Polarization HV
Number of Interpreters	36	32
Total Positive Detection	582.25	625.75
Average Positive Detection	16.20	19.57
Percent Positive Detection	48.70	58.70
Total False Positive Detection	0	0

Table 25

Analysis of Variance of Total Transportation Lines, Wichita, Kansas

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Sq. Variance	Ratio of Variances, F
Total	2125.97	67		
Between Region	192.07	1	192.07	6.55
Within Region	1933.90	66	29.30	

$P(F_{1,67} = 6.55) < .05$

Table 26

Detection of Total Transportation Lines, Superior, Wisconsin

	Polarization HH	Polarization HV
Number of Interpreters	32	36
Total Positive Detection in Inches	644.25	579.50
Average Positive Detection in Inches	20.00	16.00
Percent Positive Detection	53.00	42.40
Total False Positive Detection	0	0

Table 27

Analysis of Variance of Total Transportation Lines, Superior, Wisconsin

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Sq. Variance	Ratio of Variances, F
Total	3146.24	67		
Between Region	267.42	1	267.42	6.13
Within Region	2878.82	66	43.61	

$P(F_{1,67} = 6.13) < .05$

Table 28 Detection of Roads, Wichita, Kansas		
	Polarization	
	HH	HV
Number of Interpreters	36	32
Total Positive Detection in Inches	146	125.75
Average Positive Detection in Inches	4.04	3.92
Percent Positive Detection	28.00	27.00
Total False Positive Detection in Inches[1]	5	4

[1] Roads indicated as railroads

Table 29 Analysis of Variance of Total Positive Detection of Roads, Wichita, Kansas				
Source of Variation	Sums of Squares	Degrees of Freedom	Mean Sq. Variance	Ratio of Variance, F
Total	643.40	67		
Between Region	.38	1	.38	.03
Within Region	643.02	66	9.74	

$P(F_{1,67} = .03) > .05$

Table 30 Detection of Roads, Superior, Wisconsin		
	Polarization	
	HH	HV
Number of Interpreters	32	36
Total Positive Detection in Inches	254	113.75
Average Positive Detection in Inches	7.95	3.15
Percent Positive Detection	50.50	22.40
Total False Positive Detection in Inches[1]	17.75	2.25

[1] Roads indicated as railroads

Table 31 Analysis of Variance of Total Positive Detection of Roads, Superior, Wisconsin				
Source of Variation	Sums of Squares	Degrees of Freedom	Mean Sq. Variance	Ratio of Variances, F
Total	1102.30	67		
Between Region	390.27	1	390.27	36.20
Within Region	712.03	66	10.78	

$P(F_{1,67} = 36.20) < .001$

Table 32 Total Positive and False Positive Detection of Roads, Wichita, Kansas		
	Polarization	
	HH	HV
Number of Interpreters	36	32
Total Detection in Inches	151.00	129.75
Average Detection in Inches	4.20	4.05
Percent Detection	29.00	27.90

Table 33

Analysis of Variance of Positive and False Positive Roads Detected in Wichita, Kansas

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Sq. Variance	Ratio of Variances, F
Total	651.12	67		
Between Region	.16	1	.16	.01
Within Region	650.96	66	9.86	

$P(F_{1,67} = .01) > .05$

Table 34 Total Positive and False Positive Detection of Roads, Superior, Wisconsin		
	Polarization	
	HH	HV
Number of Interpreters	32	36
Total Detection in Inches	271.75	116.00
Average Detection in Inches	8.50	3.20
Percent Detection	54.00	20.30

Table 35

Analysis of Variance of Positive and False Positive Roads Detected in Superior, Wisconsin

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Sq. Variance	Ratio of Variances, F
Total	1138.60	67		
Between Region	431.65	1	431.65	40.68
Within Region	706.95	66	10.61	

$P(F_{1,67} = 40.68) < .001$

Table 36 Detection of Railroads, Wichita, Kansas		
	Polarization	
	HH	HV
Number of Interpreters	36	32
Total Positive Detection in Inches	306.75	325.50
Average Positive Detection in Inches	8.52	10.17
Percent Positive Detection	45.40	54.20
Total False Positive Detection in Inches[1]	135.00	168.50

[1] Railroads indicated as roads

Table 37

Analysis of Variance of Total Positive Detection of Railroads, Wichita, Kansas

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Sq. Variance	Ratio of Variances, F
Total	1317.51	67		
Between Region	205.85	1	205.85	12.22
Within Region	1111.66	66	16.84	

$P(F_{1,67} = 12.22) < .001$

Table 38 Detection of Railroads, Superior, Wisconsin		
	Polarization	
	HH	HV
Number of Interpreters	32	36
Total Positive Detection in Inches	270.25	282.75
Average Positive Detection in Inches	8.50	7.80
Percent Positive Detection	54.00	49.50
Total False Positive Detection[1]	101.25	180.75

[1] Railroads indicated as roads

Table 39

Analysis of Variance of Total Positive Detection of Railroads, Superior, Wisconsin

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Sq. Variance	Ratio of Variances, F
Total	1216.15	67		
Between Region	6.00	1	6.00	.32
Within Region	1210.15	66	18.33	

$P(F_{1,67} = .32) > .05$

Table 40 Total Positive and False Positive Detection of Railroads, Wichita, Kansas		
	Polarization	
	HH	HV
Number of Interpreters	36	32
Total Detection in Inches	441.75	494.00
Average Detection in Inches	12.25	15.45
Percent Detection in Inches	65.40	82.50

Table 41 Analysis of Variance of Positive and False Positive Railroads Detected in Wichita, Kansas				
Source of Variation	Sums of Squares	Degrees of Freedom	Mean Sq. Variance	Ratio of Variances, F
Total	1583.56	67		
Between Region	277.55	1	277.55	14.03
Within Region	1306.01	66	19.78	

$P(F_{1,67} = 14.03) < .001$

Table 42 Total Positive and False Positive Detection of Railroads, Superior, Wisconsin		
	Polarization	
	HH	HV
Number of Interpreters	32	36
Total Detection in Inches	371.50	463.50
Average Detection in Inches	11.60	12.88
Percent Detection in Inches	52.80	58.20

Table 43 Analysis of Variance of Positive and False Positive Railroads Detected in Superior, Wisconsin				
Source of Variation	Sums of Squares	Degrees of Freedom	Mean Sq Variance	Ratio of Variances, F
Total	1482.69	67		
Between Region	31.33	1	31.33	1.42
Within Region	1451.36	66	21.99	

$P(F_{1,67} = 1.42) > .05$

Table 44 Detection of Bridges, Wichita, Kansas		
	Polarization	
	HH	HV
Number of Interpreters	36	32
Total Positive Detection	566	199
Average Positive Detection	15.70	6.20
Percent Positive Detection	78.80	31.00
Total False Positive Detection	1	11
Ratio Positive/False Positive Detection	566 to 1	18 to 1

Table 45

Analysis of Variance of Total Positive Bridges, Wichita, Kansas

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Sq. Variance	Ratio of Variances, F
Total	2116.75	67		
Between Region	1530.05	1	1530.05	172.30
Within Region	586.70	66	8.88	

$P(F_{1,67} = 172.30) < .001$

Table 46 Detection of Channel Marker Traversing Water, San Diego, California		
	Polarization	
	HH	HV
Number of Interpreters	34	34
Total Positive Detection	82	10
Average Positive Detection	2.40	0.29
Percent Positive Detection	48.00	5.80
Total False Positive Detection	25	28
Ratio Positive/False Positive Detection	3.3 to 1	.35 to 1

Table 47

Analysis of Variance of Total Positive Detection at Channel Marker Traversing Water, San Diego, California

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Sq. Variance	Ratio of Variances, F
Total	165.34	67		
Between Region	67.14	1	67.14	45.99
Within Region	98.20	66	1.46	

$P(F_{1,67} = 45.99) < .001$